

## CHANNELED PROPAGATION OF SOLAR PARTICLES

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1 Introduction *Bartley et al* (1966) and *McCracken and Ness* (1966) identified bundles of interplanetary magnetic field (IMF) lines that differed in direction from the interplanetary field lines in which they were imbedded. These bundles, called filaments by the authors, differed in direction by as much as several tens of degrees from the surrounding field. The filaments were first noticed due to the large and sudden change in flow direction of highly anisotropic solar flare protons in the energy range 1 to 13 MeV. Passage of the filaments over the spacecraft required a few hours, implying a diameter for the filaments of approximately  $3 \times 10^6$  km at a distance of 1 AU from the Sun. In 1968, *Jokipii and Parker* used *Leighton's* hypothesis of random walk of magnetic field lines associated with granules and supergranules (1964) to develop a picture of an interplanetary medium composed of a tangle of field lines frozen into the solar wind, but whose feet were carried about by the random motions at the solar surface. *Jokipii and Parker* noted that using a correlation length of 15,000 km — about the radius of a supergranule — the magnetic structure would be  $3 \times 10^6$  km in size at 1 AU. This is close to the size of the filaments as determined by *Bartley et al* and *McCracken and Ness*. These workers did not find changes in the solar particle intensity, anisotropy ratio or energy spectrum as the spacecraft entered the filament.

In this paper we analyze further the phenomenon of interplanetary filamentary structure. We have identified about 50 such well-defined structures in 1978 and 1979, mainly on the basis of intensity changes in fluxes of solar electrons of energy 2 to 10 keV. Ion intensity changes are often found to accompany the changes in electron intensity. We have made use of simultaneous observations of solar wind plasma and magnetic field on the ISEE-3 spacecraft in order to further characterize interplanetary filament structure.

2 Discussion Figure 1 shows a solar flare particle event as seen at 1 AU on the ISEE-3 spacecraft. After the impulsive phase, the electron intensity decays and the slower moving ions begin to appear at about 1800 UT. At 2000 UT the low energy electrons and the ions abruptly increase in intensity. About 6 hours later the particle intensity suddenly decreases. In this case, there are no well-defined changes in the solar wind or IMF parameters with which to associate the particle intensity changes. Of further interest is the small solar flare particle injection which begins at about 0100 UT on 21 May. From the observed velocity dispersion in the higher energy channels, we would expect the arrival of 2 keV electrons sometime after 0200 UT. The absence of a new injection of electrons at this time in the lowest energy channels could be simply due to the absence of low energy electrons in the flare. This seems unlikely to us since, in the many such flare events observed on ISEE-3, we almost always find a rising spectrum down to the lowest energies. We prefer to interpret the effect as being due to location of the small flare within the region of field lines which define the filament. After the filament passes over the spacecraft, electrons from the small flare can no longer reach the spacecraft. The presence of particles from the earlier flare for many hours before and after the passage of the filament implies that the particles from this flare were injected into a much larger spatial region than was the case for the smaller flare. Figure 2 shows that the angular distribution of the low energy electrons differs significantly from that in the surrounding IMF. Just before entry into the filament, the pitch angle distribution was nearly isotropic (I in Figure 2). Inside the filament, the percentage of the

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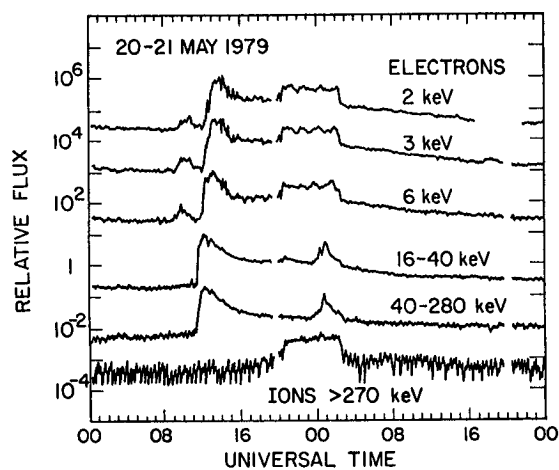


Figure 1 A broad filament interrupts the decay of a solar flare particle event for about 6 hours. The filament evidently connects the spacecraft to a place in the solar atmosphere where the emission of solar particles is greater than in the surrounding regions.

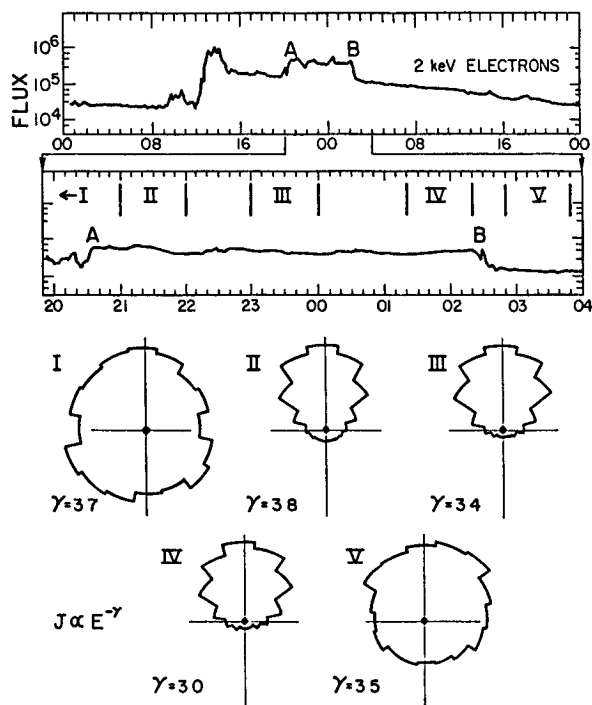


Figure 2 The pitch angle distribution of the low energy electrons in the filament shows a strong flow of particles away from the Sun. The energy spectrum of the electrons inside and outside the filament do not differ much, perhaps indicating the particles in the filament also come from the flare which began at 1107 UT.

electrons directed back toward the Sun is very small. After passage of the filament, the flow becomes much less anisotropic. The propagation conditions are very different for the low energy electrons inside the filament than for those in the surrounding interplanetary medium.

Figures 1 and 2 illustrate some of the features of filaments in the IMF as seen in low energy solar electrons. In this example, and in many others, there is little change in the solar wind and IMF parameters. Therefore, we will refer to particle effects such as those shown in Figures 1 and 2 as being due to particle propagation channels.

Figure 3 illustrates several features of these propagation channels. During the 24-hour interval shown, at least three of these can be identified. First, there are strong correlations with solar wind and IMF parameters. Perhaps the strongest of these is with solar wind number density.

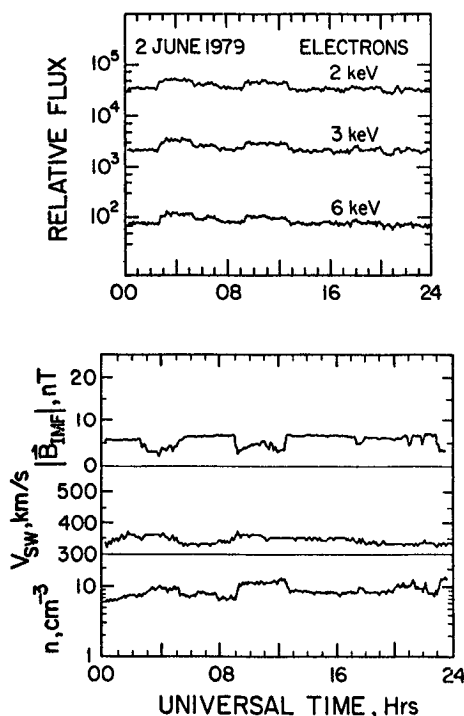


Figure 3 Particle propagation channels often occur in clusters. In this example at least three such channels can be identified. There are well-defined correlations with solar wind density and magnetic field changes.

Although not as clearly defined, solar wind speed changes appear to be spatially coincident with the particle channels. It is quite remarkable that the relative magnetic field decreases are so large. The sequence of particle channels shown in Figure 3 illustrates the tendency for them to come in clusters. Several may occur in one day, but then several days may go by without their appearance.

We have selected 37 of the most clearly defined examples of particle channels and, using solar wind velocity and IMF direction, calculated the spatial extent of each channel. The result is  $3.7 \pm 2.3 \times 10^6$  km, where we have given the average and the average deviation. We have not attempted to correct these numbers for geometrical effects based on assumed cross-section shapes for the channels. Our average value is somewhat higher than

that obtained by *Bartley et al*, but the agreement is nonetheless good

3. Conclusions Finally, we summarize a few of the results obtained to date

1) Particle propagation channels tend to come in clusters separated by a few hours. Intervals of days may elapse without the appearance of these features. There is a strong tendency for the particle channels to appear in populations of solar particles which are relatively young. Conversely, the channels are relatively rare near the end of long-lived streams of solar particles.

2) Particle propagation channels are defined by particle decreases as well as increases. The channels may contain ions as well as electrons. In some channels, the ions may show an increase while the electrons decrease, and *vice versa*.

3) The angular distribution of electrons inside the particle channels often differs greatly from the angular distributions outside the channel. This implies a considerable difference in the amount of magnetic turbulence in the frequency range 1 to 10 Hz, the frequencies most effective in scattering the pitch angles of low energy electrons.

4) We believe that particle channeling characterizes much of the interplanetary medium. While the average rate of occurrence of clearly defined ("square wave") particle channels may be on the order of only one per day, there appear to be many more channels which are less well-defined.

5) Correlation with solar wind and IMF parameters is highly variable. Sometimes the channel is distinctly defined by several of these parameters, at other times one parameter may mark the channel. In one case, a tangential discontinuity marks the edges of a particle channel (*Tsurutani, Personal Communication, April, 1985*).

6) The particle propagation channels consist of magnetic field lines which trace back to a distinctly different place in the solar particle source region, presumably in the solar atmosphere, than do field lines adjoined to the propagation channels.

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